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AIAA 92-1436
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AIAA Space Programs and Technology Conference
March 24-27, 1992/Huntsville, Alabama

AIAA-92-1436

EXOATMOSPHERIC INTERCEPT- A GOLD MINE FOR SIGNATURE AND IMPACT DATA

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Abstract

On January 28, 1991 the U. S. Army Strategic Defense Command's (USASDC) Ground Based Interceptor (GBI) Project Office began a series of exoatmospheric intercepts of target re-entry vehicles with ground launched missiles. Space provides a unique environment to gather a large volume of pre- and post-impact data. This data supports not only the GBI Project but also is useful to many other USASDC and Strategic Defense Initiative Organization (SDIO) Projects and Directorates. The test was conducted at the U. S. Army Kwajalein Atoll (USAKA) located in the Marshall Islands in the Central Pacific. A variety of sensors and airborne platforms were used to provide both a broad spectrum of data and backup collection capabilities. These sensors included the interceptor itself (prior to impact), a fly-along Observer Package, two different types of aircraft, and the radars at USAKA. Future intercepts will use these and other sensor assets to optimize and increase the data collected. The pre-impact data provided a wealth of target signature data across the electromagnetic spectrum. One application is the validation of the various signature generation codes and simulations. The post-impact data provided impact signatures and

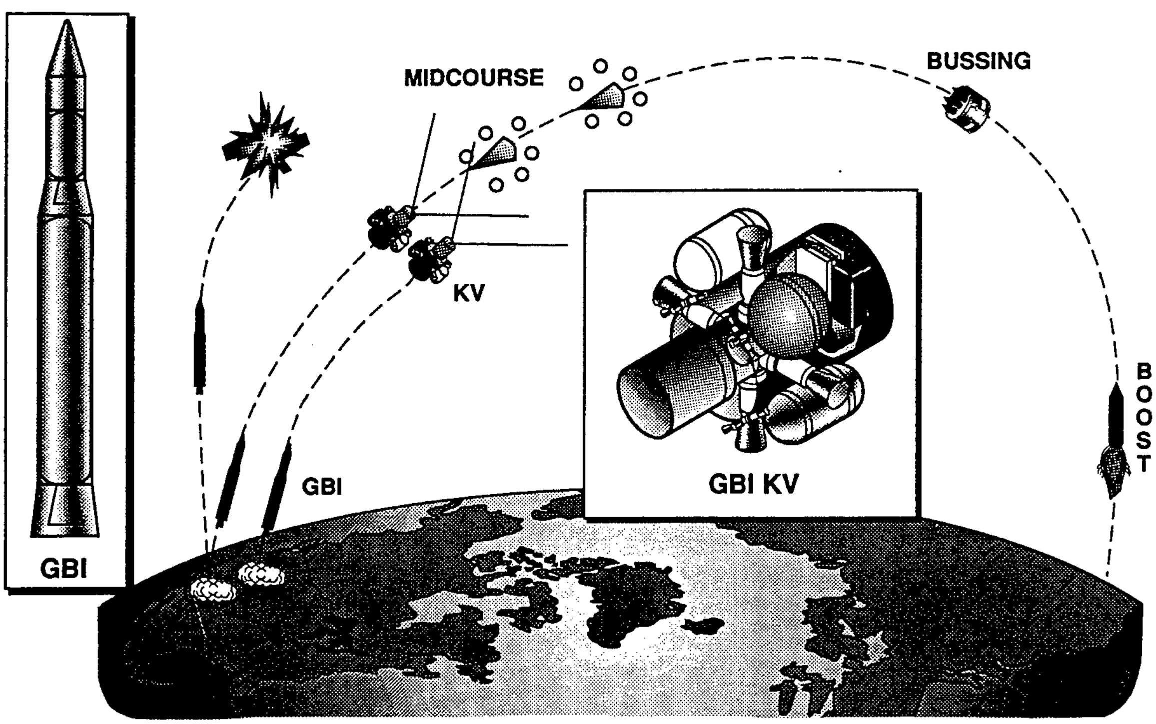

Figure 1. Ground Based Interceptor

characterization of the debris clouds. The primary applications of this data are in terms of RV lethality, kill assessment, and space debris interaction.

GBI Program

The Ground Based Interceptor, shown in Figure 1, is a low cost, non-nuclear, hit-to-kill interceptor under development by the USASDC for the Strategic Defense Initiative Organization. The GBI's battlespace is in the region above the Earth's atmosphere. GBI is presently comprised of the Functional Technology Validation (FTV) flight tests and a series of GBI Dem/Val flight tests. Together, these programs form the foundation for the development of interceptors for the National Missile Defense Initial Deployment scheduled for the late 1990's and follow-on production and improvements. The purpose of the FTV flight tests is to validate low cost interceptor technologies and pursue the resolution of GBI critical issues. The GBI Dem/Val experiments develop and infuse advanced technologies and promote competition to enable transition into the Engineering and Manufacturing Development Phase (EMD) of the Defense Acquisition Process. GBI is the foundation for the initial deployment architecture, thereby dictating that GBI use the best technology available to ensure a low risk, robust National Missile Defense.

GBI Operational Overview

The Ground Based Interceptor (GBI) is one of the elements of strategic defense and consists of an interceptor, launch site, ground support equipment, associated personnel, and support services. The elements of the defense system are linked through the Command and Control Element (CCE) to efficiently coordinate the use of sensor and weapon assets.

The GBI engagement scenario is based on sensor subsystems detecting, identifying, and designating hostile RVs (to the extent possible) and transmitting the tracking data to the CCE. The CCE determines the path of the target based on this data from the surveillance and tracking systems and plans a GBI engagement. Launch commit parameters are sent from the CCE to the GBI base, and prior to launch, trajectory parameters are downloaded from the launch site to a specific interceptor. After launch, the first stage booster separates and initiates the second stage booster. The kill vehicle (KV) separates as the second stage burns out and then repositions itself pointing the seeker field-of-view (FOV) to the predicted target position. Divert maneuvers are performed to adjust the trajectory for boost errors and in-flight updates of the target's track. As the seeker is uncapped, the target and any associated objects will be acquired. The target is designated using pattern matching algorithms or onboard discrimination capability. Once the target has been designated, the KV transitions to track mode and performs its final trajectory adjustments. In the terminal homing mode the KV selects an aimpoint on the target body in order to maximize its probability of kill. Just before impact a kill enhancement device (KED) may be deployed for added insurance of collision and lethality. Destruction of the target is accomplished by physical impact with the KV or the associated KED. The intercept event can be monitored by radars and tracking systems for final kill assessment and communicated to the CCE for further battle management action if required. This operational overview is the basis of the FTV flight test program.

FTV Program Overview

The FTV Program consists of a design and development program culminating in flight tests to demonstrate the ability of the GBI to achieve a non-nuclear, exoatmospheric, kinetic energy kill of an incoming RV using currently available technology. The FTV Program Phase has the objective of validating the operational GBI concept by demonstrating target handover capability, in-flight

Figure 2. Launch Facilities on Meck Island at USAKA

updates and course corrections, target designation, endgame discrimination, and homing and intercept of representative RV targets in the presence of simple countermeasures.

Under GBI Project Office guidance, Lockheed (LMSC) and its subcontractors have built and tested the FTV kill vehicles and are conducting the interceptor flight demonstrations. The target complex is launched from Vandenberg AFB (VAFB) in California and consists of a medium RV and decoy balloons. The interceptor is launched from Meck Island at USAKA. The USAKA range instrumentation consists of tracking radars, telemetry receiving and recording systems, optical tracking instruments, Global Positioning System (GPS) ground stations, flight safety, and timing and communications equipment. Meck Island facilities, shown in Figure 2, include the launch control building, missile assembly building, access stand, and launch cell.

The FTV Air Vehicle, shown in Figure 3, is broken down into three main sections which are the booster, booster adapter (BA), and kill vehicle (KV). The booster is an Aires II configuration which consists of refurbished Minuteman I second and third stages with shortened nozzles and an added custom built aft skirt assembly. The BA is fabricated to interface between the kill vehicle and booster and to provide structure for the OP and telemetry equipment. The kill vehicle is designed for easy assembly and access to components which are directly mounted to the primary structure. The scanning two-color HgCdTe Long-Wave Infrared (LWIR) seeker features warm optics and an inflight cooled focal plane. The propulsion and reaction control consists of a bipropellant divert system and a cold gas attitude control system. The avionics and IMU are modified off-the-shelf hardware. The KED is an inflatable bag used to negate the effects of aimpoint selection countermeasures.

The FTV mission, shown in Figure 4, begins with a simulated threat RV, built by Sandia National Laboratories, launched on a Minuteman I from VAFB on a trajectory to the USAKA area, 5000

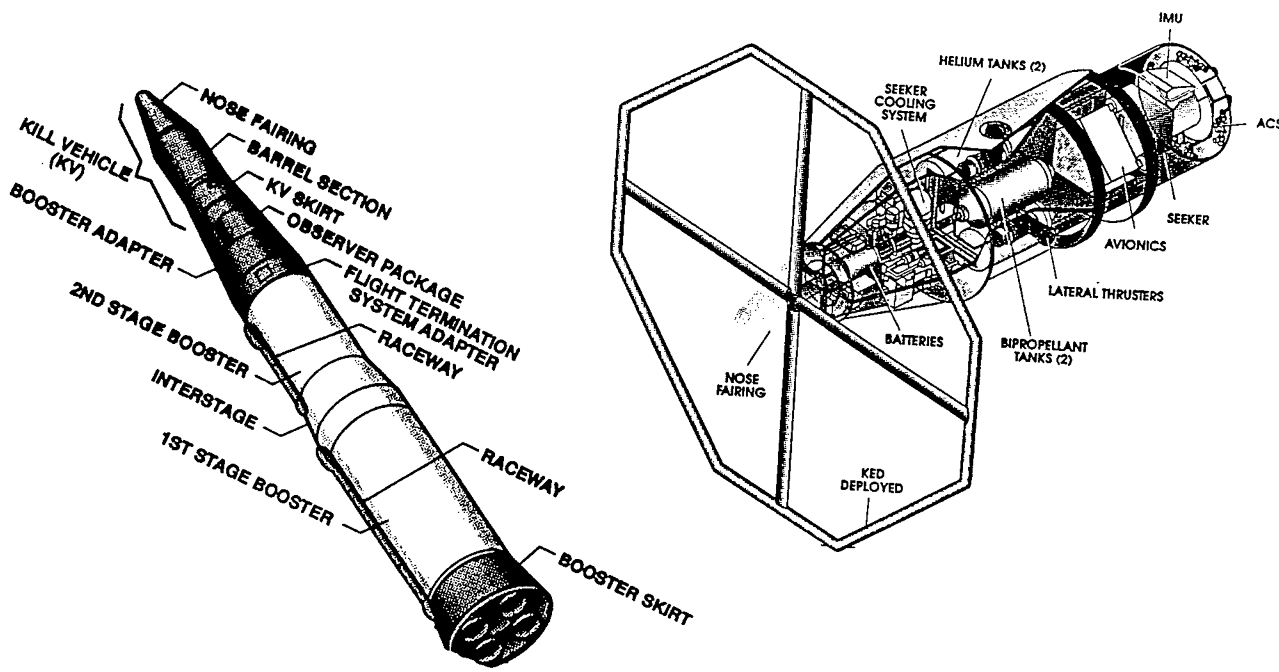

Figure 3. FTV Air Vehicle and Kill Vehicle Configurations

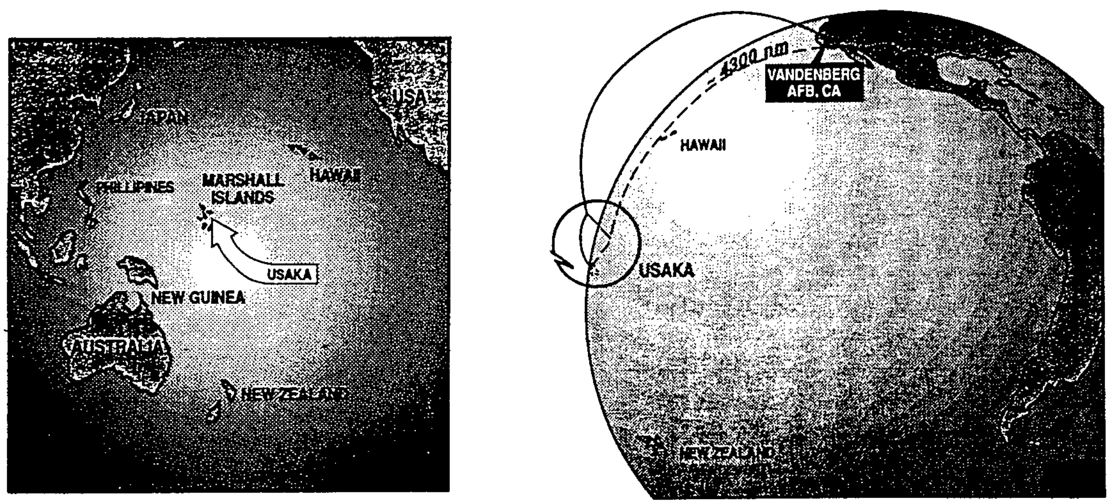

Figure 4. FTV Mission Overview

miles away. The target and its attendant decoys, have signatures typical of current threats. Equipment in the target vehicle allows it to be tracked by the Kwajalein based Global Positioning System (GPS) Translator Processing Station (TPS). The GPS data provides target position and velocity information during flight.and is used to calculate a predicted intercept point and time. The mission and launch control software computes a flyout trajectory, and the required constants are downloaded to the interceptor's avionics package. Following launch, the interceptor is also tracked using the GPS/TPS system. TPS determines the target and interceptor state vectors and transmits this data to the mission control console for uplink to the kill vehicle. Following KV separation

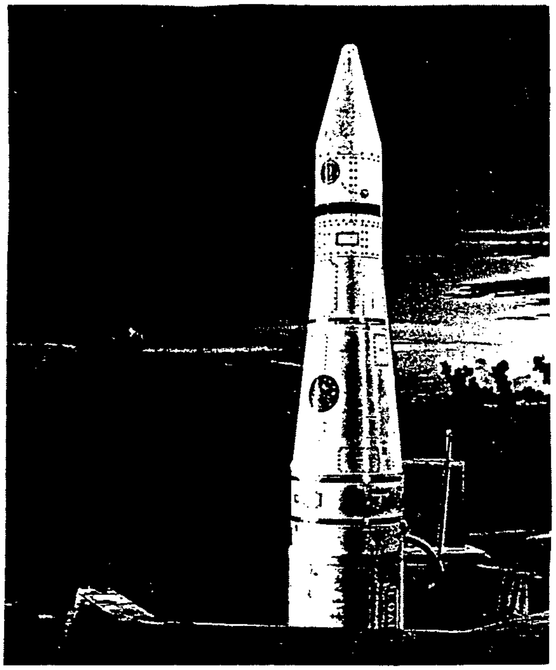

Figure 5. FTV Interceptor

from the booster and booster adaptor, the KV then performs divert maneuvers, based on the uplink message, to place it on an approximate intercept course. The LWIR seeker on board the KV performs target acquisition, designation, and closed loop track. Following the final endgame divert maneuvers, the KV intercepts and destroys the incoming RV. An Observer Package (OP) mounted in the booster adaptor follows a trajectory parallel to the KV. The OP contains sensors which point toward the predicted intercept point. The OP views the intercept at close range and collects scientific data. The OP stores this data and then telemeters it back to receiving stations on the ground.

FTV Accomplishments

The FTV Program is a major step from the previously successful Homing Overlay Experiment (HOE) in the areas of air vehicle miniaturization, functional reallocation, and life cycle cost reduction. The KV propulsion and reaction control system uses a bonded rolling diaphragm fuel tank design which reduces the weight and improves expulsion efficiency with precise center of gravity control. The KV infrared seeker design is the first exoatmospheric demonstration of a fixed body seeker. Dormancy, the basis of operational and support cost reduction, is demonstrated through rapid cryostat operation to achieve in-flight seeker cooldown. The KED design reduces the need for precise lethal aimpoint selection and increases interceptor kill capability against responsive threat countermeasures. The flight software implements velocity feedback for precise divert control, inflight measurement of thruster performance for accurate homing, scene matching target designation, closely spaced object discrimination, and target aimpoint selection in addition to basic signal processing and tracking functions. Additional advances resulting from FTV include high power density thermal batteries, exploding foil initiators for flight termination, and GPS translator demonstration. The FTV not only resolves functional issues but validates significant technology advances for GBI design consideration.

FLIGHT SUCCESS !!

The first FTV flight test vehicle (Figure 5) was flown from the Army's ballistic missile test range at Kwajalein in January 1991. This highly successful intercept of a mock ICBM warhead above the atmosphere (Figure 6) demonstrated the achievements made by the GBI Project. The interceptor correctly

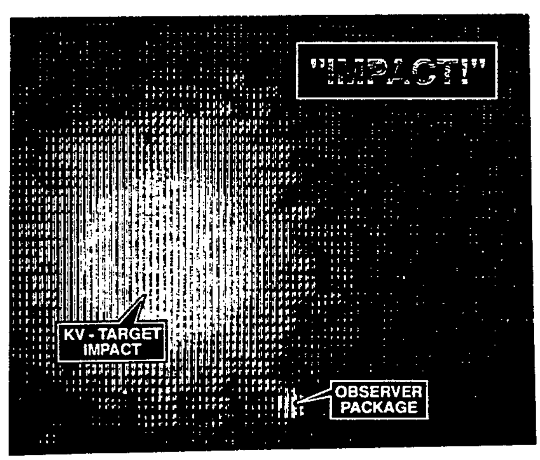

Figure 6. Mission Success

selected the RV from the decoys and destroyed the target thereby accomplishing the second successful intercept in history and the first intercept of a countermeasured target.

Although success was obvious at the moment of intercept, most of the benefit to the GBI Program has been obtained through the post-mission analysis of the resulting data. Interceptor performance and seeker data were telemetered from the kill vehicle throughout its flight, and the fly-along Observer Package provided detailed data on the intercept event. Multiband infrared and visible data was also collected by the High Altitude Learjet Observatory (HALO) and Cobra Eye observation aircraft both during and following intercept. Extensive radar data was collected both pre and post-intercept by the Kiernan Reentry Measurements Site (KREMS) radars located on Roi-Namur. It was through this wealth of broad band multi-spectral data that the real success of the FTV-1 mission is measured.

Kill Vehicle Data Collection

The kill vehicle's major hardware components and their primary functions are illustrated in Figure 3 and include: the seeker which performs acquisition and track of the threat complex; the propulsion and reaction control system which provides the lateral divert velocity necessary to adjust the kill vehicle's trajectory; the attitude control system that maintains the proper vehicle orientation; the inertial measurement unit (IMU) which senses the vehicle's movements to provide precise knowledge of its position and velocity in space; and the avionics package which is the computer brains that controls the vehicle's operation. Throughout the flight, health and status as well as operational data was telemetered on all of the KV systems and recorded on the ground in order to provide detailed assessments of the performance of each component and the corresponding flight software.

Based on data recorded during the mission, it has been possible to evaluate and verify the interceptor's boost, divert, and guidance and navigation performances. These factors include: boost stability and control margins, boost and KV separation shock environments, divert thrust levels, variations in thrust alignment, response times for divert and attitude control systems, and the KV's response to inflight guidance and target updates.

Seeker telemetry data was received and recorded during its entire operation which included a star sighting, cold space background checks, and track of the target complex. This data has verified performance of in-flight cooling of the detector focal plane, the accuracy of the seeker calibration, and its ability to adjust detector gains and offsets in-flight. It has also provided valuable information on characterization of detector noise, the effects of divert burns on seeker background irradiance, and the vibrational response of the seeker to divert lateral shocks. Seeker data on the target complex has supported evaluation of exoatmospheric infrared signatures and discriminants for the RV and the balloon decoys. This information is critical to ensure confidence in the design and operation of the next generation of infrared seekers.

One of the most significant results of the FTV-1 mission has been the verification and validation of the ground and flight software necessary to perform exo-intercepts. Ground software performs all mission and launch control processes and launch operations. This includes: interceptor warm-up functions; target track processing, correlation, and selection; engagement planning; and launch commit message formulation. Flight software performs all interceptor functions following receipt of the commit message which includes: boost control and staging; KV navigation, guidance, and control; update processing; calculation and execution of all lateral divert and attitude corrections; seeker signal and data processing; scan-to-scan correlation; threat object map metric target designation; track processing; terminal imaging; and final aimpoint selection. Whereas all hardware and software did not perform flawlessly, there was sufficient margin and contingencies built into the software that allowed for a successful mission. The majority of thissoftware is directly applicable to the software required to support a fielded operational national defense system.

Observer Package Data Collection

The Observer Package (OP), shown in Figure 7, is a collection of sensors and scientific instruments mounted in the interceptor's booster adaptor. The BA remains attached to the spent second stage booster and follows a parallel trajectory with the KV providing a standoff distance of 5-10 kilometers at intercept. The OP line of sight is oriented to align with the expected intercept point. Its purpose is to measure and record the phenomenology of the intercept event in order to better understand the physics of exoatmospheric hypervelocity impacts. With the relative closing velocity greater than 7.5 kilometers per second the solid materials of the target and the KV behave more like fluids and appear in essence to almost pass through one another. The resulting debris fields generally follow their previous ballistic trajectories.

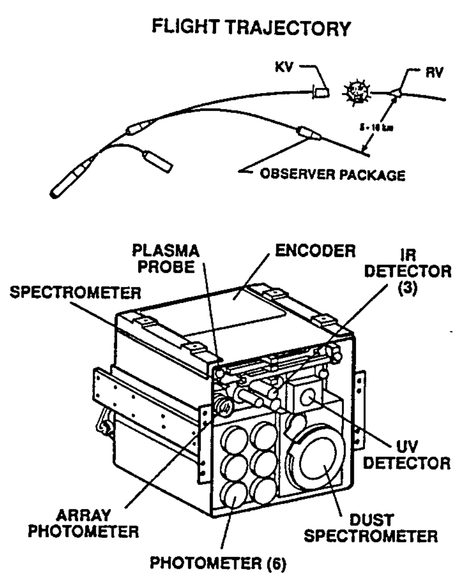

Figure 7. FTV Observer Package

The OP sensor suite includes visible photometers, infrared detectors, ultraviolet detector, dust spectrometer, visible spectrometer, and plasma probes. The OP was designed to provide very high speed data collection (10 KHz to 40 MHz) with near continuous coverage from the extreme ultraviolet to the long wave infrared (.01 to 10 μm) wavelengths. Due to some problems with the OP battery and the timing circuit, data during the intercept event was only collected at 122 Hz to 10 KHz rates, but even these reduced data rates provided significant results. The primary phenomena measured by the OP include infrared and visible flash intensity and duration, intercept debris dust sizes and velocities, debris cloud expansion rates, plasma density, and electric field depletion. This data is directly applicable to evaluating RV lethality and kill assessment capability as well as establishing debris avoidance criteria for follow-on interceptors.

In addition, the BA and OP also provided data following the intercept event as it re-entered the Earth's atmosphere. This data included background irradiance and vehicle control stability which is necessary for designing interceptors that will be able to operate in the high endo-atmosphere.

Radar Data Collection

The KREMS Radar facilities on Roi-Namur, shown in Figure 8, consist of four primary radars: ALTAIR (VHF and UHF), TRADEX (L-band and S-band), ALCOR (C-band), and MMW (Ka-band). During the FTV missions, these radars collected extensive multi-frequency data of excellent quality from prior-to intercept through debris reentry.

In the period prior to intercept, these radars were able to collect

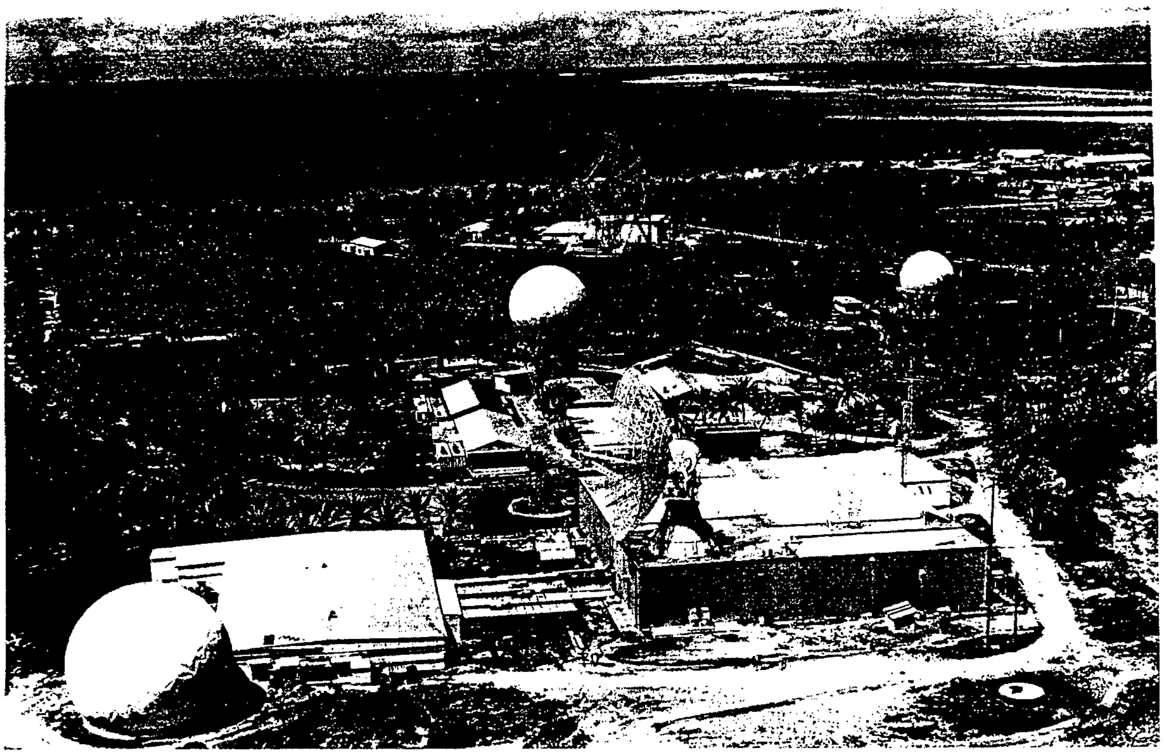

Figure 8. Kiernan Reentry Measurements Site at USAKA

considerable data on the RV and balloon radar cross-section (RCS) signatures. During this period the two decoy balloons were deployed from the base of the RV. The radars were able to accurately determine RV dynamics, balloon ejection velocity, balloon inflation, balloon dynamics, and the mass of the balloons.

In the period following intercept, the radars collected data on the intercept flash, the number and size of the debris fragments, and the average expansion rate of the debris clouds. The balloons were not destroyed by the intercept event, but the radars were able to accurately measure significant perturbations in their trajectories. As the balloons started to re-enter, the radars detected the sudden deceleration along the balloon's trajectory due to the onset of atmospheric drag.

Airborne Data Collection

Two airborne sensor platforms, shown in Figure 9, were used in support of the FTV-1 mission. The objectives of the Cobra Eye and HALO aircraft were to collect as much data as possible on the target complex, the intercept event, and any resulting debris. Their sensor suites consisted of a variety of MWIR, LWIR, and visible sensors.

Although there were considerable high altitude cirrus clouds in the test area on the flight date, both aircraft were able to collect valuable data for post mission analysis. Primary results from these aircraft include: excellent video footage of the intercept event; time resolved images of the intercept flash in SWIR, MWIR, LWIR, and visible wavebands; debris characterization; and balloon heating rates during reentry and demise.

Remaining Issues

FTV flights address many of the issues underlying midcourse intercept. Navigation and guidance accuracy, threat object map handover, aimpoint selection, lethality, and hit-to-kill have been resolved during the FTV flights.

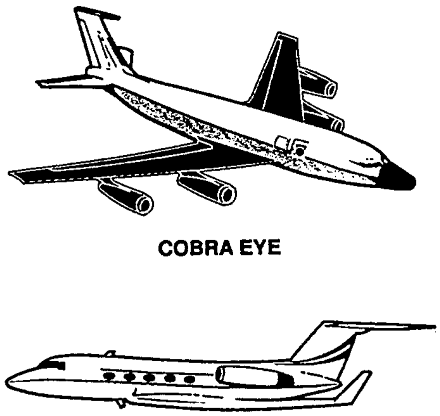

Figure 9. Observation Aircraft

Affordability and producibility have also been addressed during FTV (and readdressed as technology provides improvements). The remaining issues which are critical to robust interceptor capability are on-board discrimination and hardening for operation in a nuclear environment. An interceptor which can resolve and discriminate closely-spaced objects not resolvable by precommit sensors will always provide a lower cost per kill. Furthermore, an interceptor must be hard to the nuclear environment to ensure reliability.

On-board discrimination is the central issue of the program. How much, and how well the interceptor can do it, are questions that hardware testing will answer. A very broad approach to the problem is in order. Discrimination testing will take place using a wide variety of on-board sensors. Long wave IR sensors with very long acquisition ranges will permit the time needed for temperature discrimination. Long range visible sensors, limited only by the earth's geometry, will permit imaging and rate measurements. Ultraviolet wavebands will also be available. Active RF sensors will measure doppler returns for signature modulations evidencing rotation rates, rate changes, and vibrations. Concurrently, all forms of discrimination algorithms will bear on the problem. Statistical pattern recognition, expert systems, and especially real-time learning techniques will be developed. The flight tests will exploit the potential in real-time observation of intercept phenomenology available to trailing interceptors and precommit sensors. The program will develop data fusion techniques to exploit data combination between interceptors and precommit sensors. At the same time, all threat objects will be modeled intensively to study their high frequency characteristics and their susceptibility to high frame rate, high resolution, and close range observation afforded by interceptor discrimination.

Conclusion

The GBI Project has made significant strides in resolving the issues associated with exoatmospheric intercepts of ballistic missile RVs by ground launched interceptors. The FTV missions have provided the realistic environments and flight conditions required for true system performance verification. The extensive database resulting from the FTV missions have provided a wealth of information and will continue to be analyzed. The applications of this database span from interceptor performance and optical/radar signature evaluation to disciplines concerned with lethality, kill assessment, debris characterization, and hypervelocity impact phenomena. Due to the nature of this program, most of this database is classified. Special requests for access should be handled through the USASDC GBI Project Office in Huntsville, AL.

The GBI Project is continuing with its development and flight testing of advanced interceptor concepts and is rapidly progressing toward the final development, production, and initial deployment of interceptors for the National Missile Defense.

Accession Number: 4272

Publication Date: Mar 24, 1992

Title: Exoatmospheric Intercept - A Gold Mine for Signature and Impact Data

Personal Author: Katechis, J.; Caldwell, J.

Corporate Author Or Publisher: USASDC, Huntsville, AL; Teledyne Brown Engineering, Huntsville, AL
Report Number: AIAA 92-1436

Comments on Document: AIAA Space Programs and Technology Conference March 24-27, 1992/Huntsville, AL

Descriptors, Keywords: USASDC GBI Intercept Target RV Sensor Missile GPS Kill Vehicle

Pages: 00009

Cataloged Date: Jan 27, 1993

Document Type: HC

Number of Copies In Library: 000001

Record ID: 26107

Source of Document: AIAA